205, Rev. B
34-m and 70-m Command

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Change Log

Rev	Issue Date	Affected Paragraphs	Change Summary
Initial	1/15/2001	All	Initial Release
A	12/15/2002	All	Provides description and capabilities of new DSN command equipment
B	12/15/2009	Many	Replaced DSMS with DSN. Removed references to the decommissioned 26-m subnet. Updated Table 1 and replaced previous Figure 3 with the current Figures 3, 4 & 5.

Note to Readers

There are two sets of document histories in the 810-005 document that are reflected in the header at the top of each page. First, the entire document is periodically released as a revision when major changes affect a majority of the modules. For example, this module is part of 810-005, Revision E. Second; the individual modules also change, starting as an initial issue that has no revision letter. When a module is changed, a change letter is appended to the module number on the second line of the header and a summary of the changes is entered in the module's change log.

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1 Introduction

1.1 Purpose

This module provides performance parameters for the elements of the Deep Space Network (DSN) that are exclusively used for sending commands to spacecraft. It is intended to assist the telecommunications engineer in designing an uplink (or forward space link) that is compatible with currently installed DSN equipment. It also contains brief descriptions of future enhancements that have been proposed for this equipment and capabilities that are being maintained for legacy customers using the previous generation of command equipment.

1.2 Scope

The discussion in this module is limited to command equipment used with the Deep Space Network (DSN) 70-m antennas and the 34-m antennas. Detailed performance of equipment used for purposes in addition to command is covered elsewhere in 810-005. Information on antennas, exciters, and transmitters have been included as a convenience and should be verified against their primary source. In particular, the following modules should be considered:

101 70-m Subnet Telecommunications Interfaces,

103 34-m HEF Subnet Telecommunications Interfaces,

104 34-m BWG Stations Telecommunications Interfaces, and

301 Coverage and Geometry.

2 General Information

Each antenna in the DSN is capable of sending commands to one spacecraft at a time. Each Deep Space Communications Complex (DSCC) contains one 70-m and from two to five 34-m antennas. There are two types of 34-m antennas. The first is the so-called high-efficiency (HEF) antennas that have their feed, low-noise amplifiers, and transmitter located on the tilting structure of the antenna. These antennas were named when a less-efficient 34-m antenna was in use by the DSN and the name has survived. The efficiency of all DSN 34-m antennas is now approximately the same. The second type of 34-m antenna is the beam waveguide (BWG) antenna where the feeds, low noise amplifiers and transmitters are located in a room below the antenna structure and the radio frequency energy is transferred to and from the antenna surface by a series of mirrors encased in a protective tube.

The capabilities of each antenna type and, in some cases, of the individual antennas are different and must be considered in designing a command link. Often, the selection of antenna for uplink will depend on the downlink frequencies it supports. Table 1 lists the uplink and downlink frequency ranges for each antenna type and provides approximate ranges for uplink Effective Isotropic Radiated Power (EIRP). The modules referred to above should be consulted for exact values and other parameters. The telecommunications link designer is cautioned against making designs dependent on the 70-m antenna, as there is only one per complex and it subject to severe scheduling constraints.

Table 1. Capabilities of DSN 70-m and 34-m Antennas

Antenna Type	Complex/Site	Uplink Freq (MHz)	TXR Power (W)	EIRP (dBW)	Downlink Freq (MHz)	Gain (dBi) / G/T (dB/K)
34M BWG	Goldstone, CA USA	S: 2025 - 2120	20,000	78.7 - 98.7	S: 2200 - 2300	56.8 / 41.3
	Canberra, Australia	S: 2025 - 2120	20,000	78.7 - 98.7	S: 2200 - 2300	56.8 / 40.8
	Madrid, Spain	S: 2025 - 2120	20,000	78.7 - 98.7	S: 2200 - 2300	56.8 / 41.0
	Goldstone, CA USA	X: 7145 - 7235	20,000	89.5 - 109.5	X: 8400 - 8500	68.3 / 52.8
	Canberra, Australia	X: 7146 - 7235	20,000	89.5 - 109.5	X: 8400 - 8500	68.3 / 53.7
	Madrid, Spain	X: 7147 - 7235	20,000	89.5 - 109.5	X: 8400 - 8500	68.3 / 53.8
	Goldstone, CA USA	Ka: 34200 - 34700	800	98.2 - 108.2	Ka: 25500 - 27000 Ka: 31800 - 32300	** 79.0 / 64.1
	Canberra, Australia	-		-	Ka: 25500 - 27000 Ka: 31800 - 32300	** 79.0 / 65.6
	Madrid, Spain	-		-	Ka: 25500 - 27000 Ka: 31800 - 32300	** 79.0 / 64.4
34M HEF	Goldstone, CA USA	-		-	S: 2200 - 2300	56.0 / 40.2
	Canberra, Australia	S: 2025 - 2110	250	71.8 - 78.8	S: 2200 - 2300	56.0 / 40.2
	Madrid, Spain	S: 2025 - 2110	250	71.8 - 78.8	S: 2200 - 2300	56.0 / 39.6
	Goldstone, CA USA	X: 7145 - 7190	20,000	89.8 - 109.8	X: 8400 - 8500	68.3 / 54.0
	Canberra, Australia	X: 7145 - 7190	20,000	89.8 - 109.8	X: 8400 - 8500	68.3 / 54.0
	Madrid, Spain	X: 7145 - 7190	20,000	89.8 - 109.8	X: 8400 - 8500	68.3 / 54.0
34M HSB	Goldstone, CA USA	S: 2025 - 2110	200	70.7 - 76.7	S: 2200 - 2300	55.0 / 34.8
70M	Goldstone, CA USA	S: 2110 - 2118 S: 2090 - 2091	20,000 3,000	85.6 - 105.6 85.6 - 97.4	S: 2270 - 2300	63.5 / 51.0
	Canberra, Australia	S: 2110 - 2118 S: 2110 - 2118 S: 2090 - 2091	20,000 400,000 3,000	85.6 - 105.6 106.7 - 118.7 85.6 - 97.4	S: 2270 - 2300	63.5 / 50.9
	Madrid, Spain	S: 2110 - 2118 S: 2090 - 2091	20,000 3,000	85.6 - 105.6 85.6 - 97.4	S: 2270 - 2300	63.5 / 50.9
	Goldstone, CA USA	X: 7145 - 7190	20,000	95.8 - 115.8	X: 8400 - 8500	74.5 / 62.9
	Canberra, Australia	X: 7145 - 7190	20,000	95.8 - 115.8	X: 8400 - 8500	74.6 / 62.8
	Madrid, Spain	X: 7145 - 7190	20,000	95.8 - 115.8	X: 8400 - 8500	74.6 / 63.1

** Measurement of G/T in progress

Figures 1 and 2 illustrate the DSN command capabilities assuming a reference spacecraft employing a residual carrier uplink and having the characteristics specified in Table 2. These figures show that command range at low bit rates is limited by the spacecraft carrier tracking performance. At higher bit rates, the range is limited by available E_b/N_o. Figure 1 is intended to show performance during a spacecraft emergency that forces the use of an omni-directional antenna. The uplink modulation index has been intentionally lowered to 0.5 radians to direct more power to the carrier. Figure 2 assumes a more typical spacecraft configuration using a high-gain antenna and an uplink modulation index of 1.2 radians.

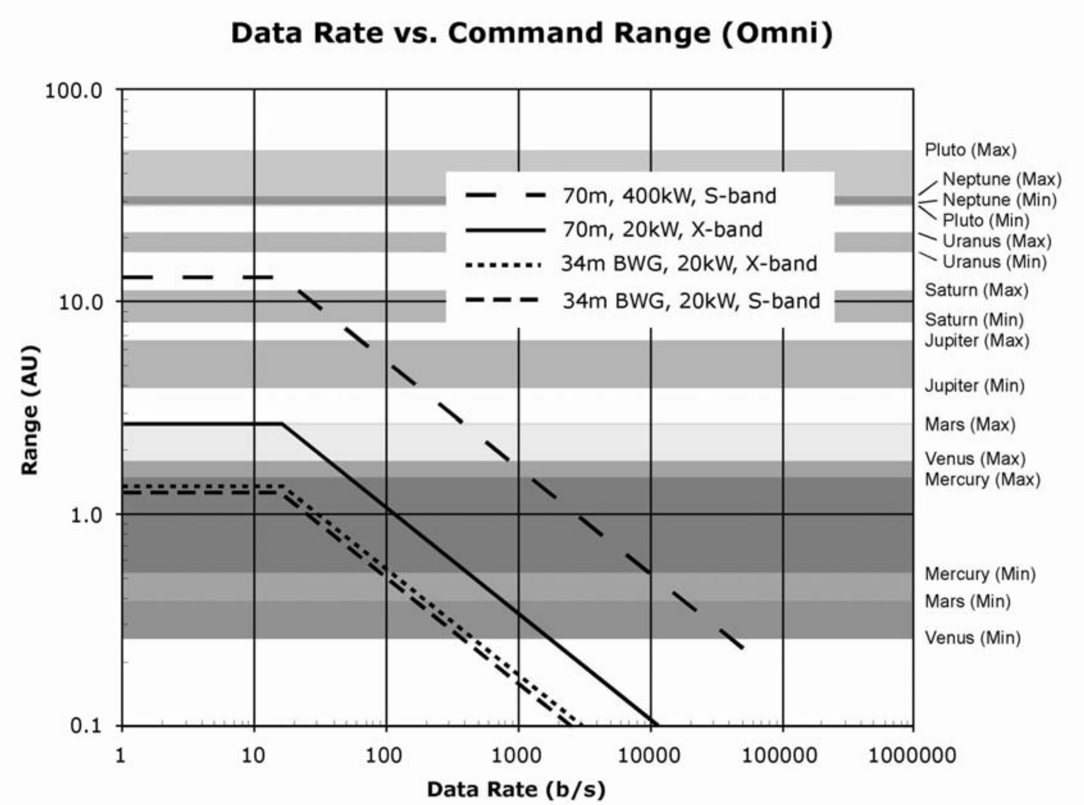

Figure 1. Maximum Command Range for a Reference Spacecraft with an Omni-directional Antenna and a 0.5 Radian Command Modulation Index.

Table 2. Reference Spacecraft Characteristics for Figures 1 and 2.

Parameter	Value
Antenna Gain less pointing loss Omnidirectional S-band Hi-gain X-band Hi-gain	 0 dB 30 dB 39.7 dB
Other RF losses	–1.8 dB
System Temperature	500 K
Carrier Loop Bandwidth	100 Hz
Required Carrier Margin	12 dB
Command Detection Losses	–1.5 dB
Required E_b/N_o	9.6 dB

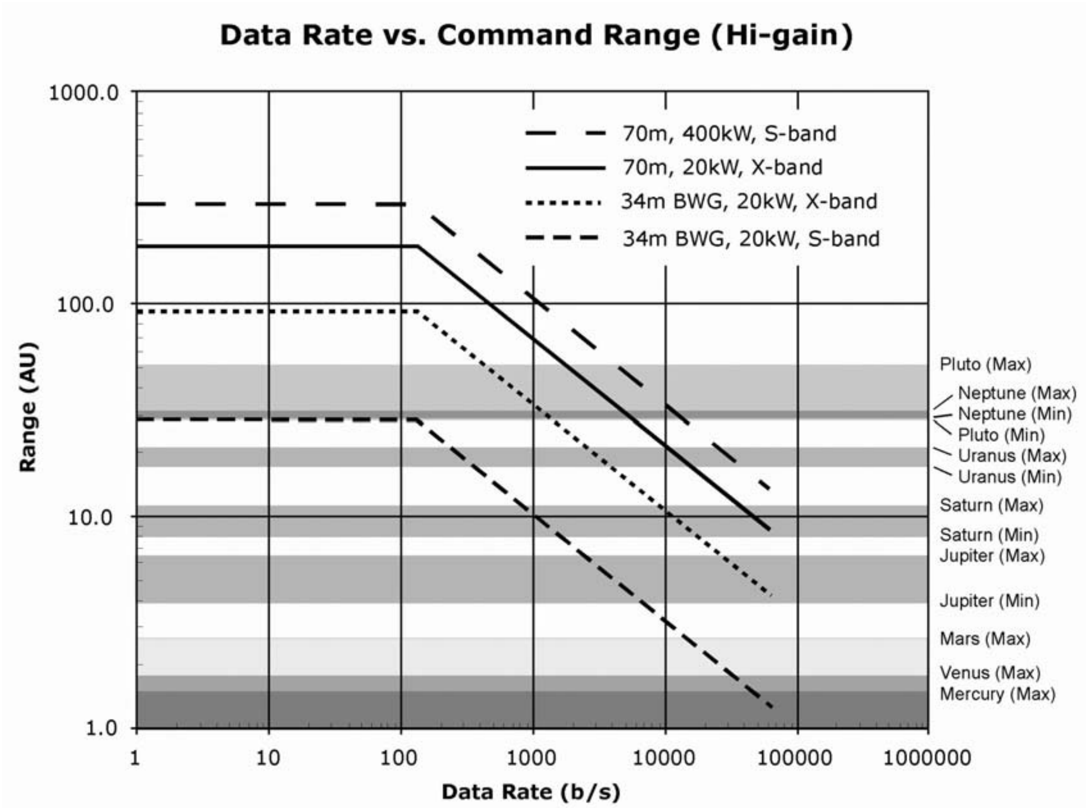

Figure 2. Maximum Command Range for a Reference Spacecraft with a High-gain Antenna and a 1.2 Radian Command Modulation Index.

Uplink data are delivered to the DSN using one of three services. The first is referred to as Stream Mode Command Radiation Service using the *Space Link Extension* (SLE) forward service, an implementation of the Consultative Committed for Space Data Systems (CCSDS) recommendation 912.1, Space Link Extension Forward CLTU Service, and is described in DSN Document 820-013, module 0163-Telecomm. See the dataflow diagram in Figure 3. The SLE forward service is an online only service including service users providing command symbols to be transferred to the spacecraft and ancillary information such as routing, ensuring the integrity of the Earth segment of the communications link, and providing the customer limited control of the command process as described in the aforementioned documents.

The second, File Mode Command Radiation Service, is provided by accessing a file of Command Link Transmission Units (CLTUs) from the Mission Operations Center (MOC) via DSN File Store where the individual CLTUs are extracted and passed on to the Ground Station for modulation onto the uplink carrier and radiation to the spacecraft. The file of CLTUs is referred to as a Spacecraft Command Message File (SCMF). See the dataflow diagram in Figure 4. This service is an online or offline store and forward service that allows management of multiple stored command files.

The third, Command Delivery Service, uses the CCSDS File Delivery Protocol (CFDP) and is available for spacecraft that employ this protocol. It is described in DSN Document 820-013, module 0213-Telecomm-CFDP. The service is provided by accessing files from the MOC via DSN File Store where the files are converted CLTUs which are then passed to the Ground Station for modulation onto the uplink carrier and radiation to the spacecraft. See the dataflow diagram in Figure 5. This is also an online or offline service that allows generalized uplink file transfer.

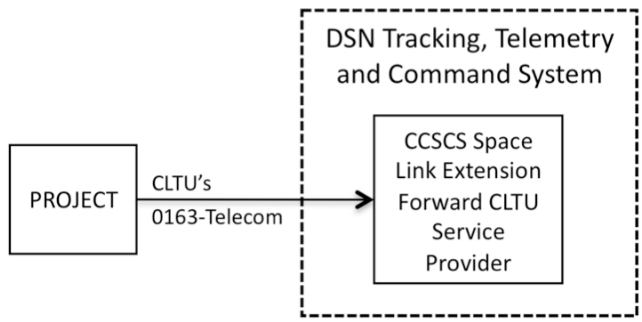

Figure 3. Space Link Extension (SLE) Forward Service Dataflow

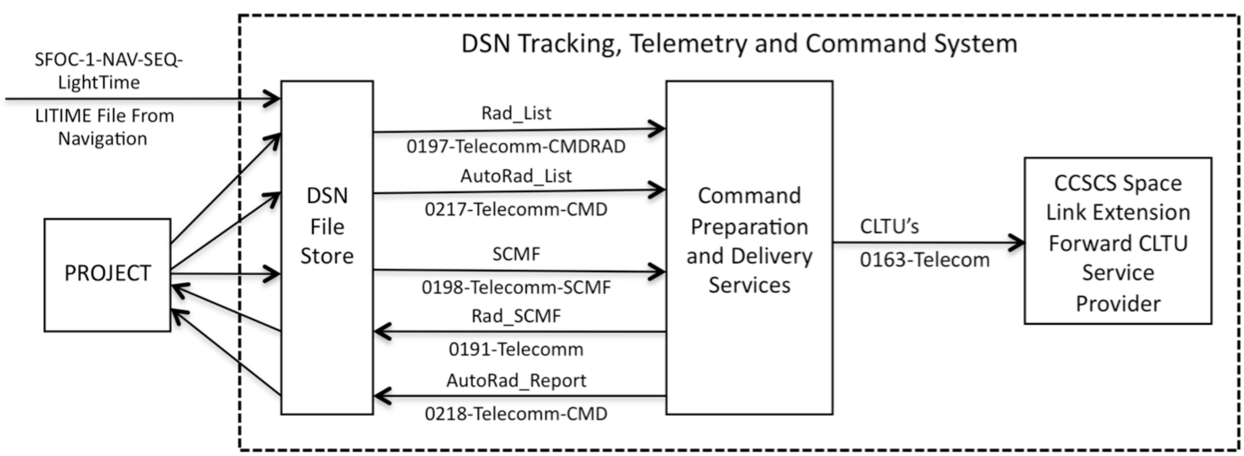

Figure 4. Command Radiation Service Dataflow – File Mode (SCMF)

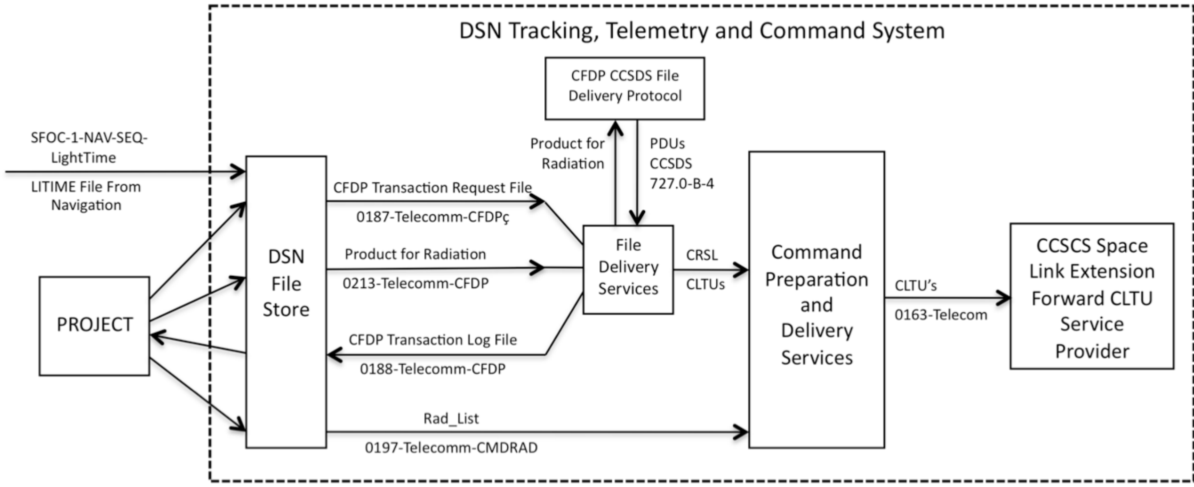

Figure 5. Command Delivery Service Dataflow – (CFDP)

The only function performed at the stations is the mechanism whereby command data are extracted from the delivery format and converted to an RF signal suitable for reception by a spacecraft. This means that all commands including prefix symbols, and command data symbols must be generated at the appropriate MOC or Project Operations Control Center (POCC). If coding such as Bose-Chaudhuri-Hocquenghem (BCH) is required, it must be accomplished before the commands are delivered to the DSN. The DSN may perform checks for format compliance, but it will not interpret nor modify the contents of any command. Neither does it guarantees error free command delivery to the spacecraft. It is up to the project to provide its own error detection and correction schemes.

The DSN has the capability to operate its command equipment without radiating commands while simultaneously recording the data stream that has been accepted from a project. A limited number of these command recordings for each project may be stored at the DSCCs for use in an emergency (such as loss of communication from an operations center during a critical mission event) to place a spacecraft in a safe condition. The procedure for the use of these recordings is beyond the scope of this document.

In addition to the interfaces by which command data are delivered to the DSN, a management interface is required for selecting the particular set of parameter appropriate for the spacecraft being supported. A discussion of this interface is contained in DSN Document 810-007, DSN Mission Interface Design Handbook (not yet published).

3 Command Parameters

The following paragraphs provide a discussion of the principal command parameters. Parameters that are a function of antenna type were summarized in Table 1. Parameters that are independent of antenna type are summarized in Table 3.

3.1 RF Power

RF power is produced by variable beam klystron amplifiers that permit saturated operation over a relatively wide power range by adjustment of the drive power and beam voltage. The 20 kW transmitters can be saturated at power levels as low as 2 kW and unsaturated operation is possible down to 200 W, The 400 kW S-band transmitter operates saturated from 200 kW to 400 kW and unsaturated operation is possible at power levels as low as 20 kW. The efficiency of the transmitters falls off rapidly as power level decreases so there is little, if any, energy savings by operating at a lower power level. On the other hand, the life of the klystrons is a function of power level so operating at reduced power should be considered wherever possible.

Table 3. Command Parameters

Parameter	Value	Remarks
RF Power Output	See Table 1	Also see modules 101, 103, and 104
Effective Isotropic Radiated Power (EIRP)	See Table 1	Also see modules 101, 103, and 104
Carrier Frequency	See Table 1	Also see modules 101, 103, and 104
Subcarrier Frequencies Sinewave Squarewave	 999 Hz – 250075 Hz 100 Hz – 1000 Hz	
Subcarrier Frequency Resolution	0.1 Hz	Sinewave and Squarewave
Harmonic and Spurious Signals (Sinewave Subcarrier)	>45 dB	Below subcarrier amplitude (dB-V)
Harmonic Response (Squarewave Subcarrier)	< 6 dB	Attenuation of 7th harmonic (dB-V)
Subcarrier Stability	$>1 \times 10^{-9}$	For all measurement times from 100 s through 12 h (derived from station frequency standard)
PCM Data Formats	NRZ-L, M, S Bi-ϕ-L, M, S	See Figure 4
Modulation Index Range Sinewave Subcarrier Squarewave Subcarrier	 0.1 – 1.52 radians 0.1 – 1.40 radians	 6 – 87 degrees 6 – 80 degrees
Modulation Index Accuracy	±10%	Of carrier suppression in dB
Modulation Index Stability	±3%	Of carrier suppression in dB over a 12-h period
Data Rates Sinewave Subcarrier Squarewave Subcarrier	 1 bps – 125037.5 bps 1 bps – 500 bps	Subcarrier Frequency/2^n, $1 \le n \le 11$
Coherency to Subcarrier	±6°	Offset between bit/symbol transitions and subcarrier zero crossings.
Data Rate Stability	$>1 \times 10^{-9}$	For all measurement times from 100 s through 12 h (derived from subcarrier stability)

Table 3. Command Parameters (Continued)

Parameter	Value	Remarks
Inter-command modulation	None (Carrier only), carrier and command subcarrier, carrier, command subcarrier and idle pattern	
Idle Pattern	8-bit repetitive	
Command Timing	0.1 s	0.1 s plus 1 – 8 bit times if idle pattern is present
Pre-track Calibration	20 m 5 m	With Transmitter warm-up or band change Transmitter already warmed-up
Availability	98.9%	
Mean-time between Command Aborts	2200 h	

The calibration process for setting RF power starts at approximately one tenth of the desired power and gradually increases over a few minutes until the desired power is reached. Therefore, changing power during a tracking pass may have unexpected results. For example, a decision to raise the power from 5kW to 20kW will result in a momentary reduction to approximately 2kW followed by a gradual increase to 20kW. A decision to lower the power from 20kW to 5kW will result in a momentary reduction to approximately 500W followed by a gradual increase to 5kW.

3.2 Carrier Frequency

The DSN considers establishment of carrier frequency to be a tracking function as opposed to a command function. Small frequency changes such as might be required for Doppler compensation will have little effect on the transmitter output. Larger frequency changes such as might be required to command two spacecraft within the same beamwidth may cause the transmitter output to vary by as much as 1-dB due to ripple across the klystron passband. Should this happen, the operator at the station will be warned that the transmitter should be re-calibrated. This warning may be ignored to no detriment other than the power output being as much as 1-dB from the requested value.

The S/X/K BWG subnet has two klystron amplifiers that share a common power supply and cooling system. Therefore, a change of band will require a minimum of 20-minutes to cool-down the klystron that is no longer needed and warm-up and calibrate the other klystron.

The S-band klystron at these stations is step-tunable to provide coverage over the entire uplink band. Changing from one band segment to another requires turning off the transmitter, changing the band segment, and re-calibrating at the new frequency.

3.3 Subcarriers

Both sinewave and squarewave subcarriers are available. Subcarrier frequencies are initialized from an entry in the activity service table but may be changed during a support activity providing no command waveform is being radiated. This technique can be used to provide a limited amount of subcarrier Doppler compensation recognizing that command modulation (including the subcarrier) must be removed when the subcarrier frequency is changed. Changing the subcarrier frequency will cause a corresponding change in data rate because these two items are coherent. See the discussion on data rate for details.

3.4 Modulation Index

The modulation index is established by applying a variable-amplitude voltage to the phase modulator in the exciter. The amplitude of this voltage can be adjusted in 255 steps of approximately 0.0065 radians. The range of 0.1 radians through 1.52 radians occupies approximately 220 of these steps. The modulating voltage is calibrated periodically at the 3-dB carrier suppression point for both sinewave and squarewave subcarriers. The calibration interval is selected to assure a carrier suppression within 10% of the specified value in dB at any time between calibrations. For example, a sinewave modulation index of 0.67 radians (38.5°) will produce a carrier suppression of 1.0 dB ± 0.1 dB. A sinewave modulation index of 1.13 radians (64.5°) will produce a carrier suppression of 3.0 dB ±0.3 dB.

The modulation index is initialized from an entry in the activity service table but may be changed during a support activity providing no command waveform is being radiated. Carrier power suppression and data power suppression as functions of modulation index angle are:

Sine-wave subcarrier:

$$\frac{P_C}{P_T}(\mathrm{dB}) = 10\log\left[2J_0^2(\theta_D)\right], \mathrm{dB} \tag{1}$$

$$\frac{P_D}{P_T}(\mathrm{dB}) = 10\log\left[2J_1^2(\theta_D)\right], \mathrm{dB}\ \{\text{first upper and lower sidebands}\} \tag{2}$$

Square-wave subcarrier:

$$\frac{P_C}{P_T}(\mathrm{dB}) = 10\log\left[\cos^2(\theta_D)\right], \mathrm{dB} \tag{3}$$

$$\frac{P_D}{P_T}(\mathrm{dB}) = 10\log\left[\sin^2(\theta_D)\right], \mathrm{dB}\ \{\text{all sidebands}\} \tag{4}$$

where

θ_D = data modulation index, radians, peak

P_T = total power

P_C = carrier power

P_D = data power

J_0 = zero-order Bessel function

J_1 = first-order Bessel Function

3.5 Modulation Losses

The bandpass of all elements in the command path with the exception of the S-band power amplifier at the 34-m S/X/K BWG stations is adequate to make modulation losses negligible over the frequency and power ranges specified in Table 1. The modulation losses at the 34-m S/X/K BWG stations are negligible provided the klystron frequency step is properly selected.

3.6 PCM Data Formats

The DSN Command System produces a pulse code modulated (PCM) waveform that is binary phase-shift keyed (BPSK) onto a subcarrier. That is, phase-shift keyed with a signaling level of ±90° and resulting in a fully suppressed subcarrier. The six supported PCM data formats are illustrated in Figure 4. The data format is established at the start of a support activity by an entry in the activity service table.

3.7 Data Rates

Bit rates for NRZ modulation and symbol rates for bi-phase modulation are available over the range of 1 to 125,037.5 bps or sps. They are derived from the subcarrier frequency generator using a binary divider of 2^n where n can be from 1 to 11. Thus, a 1 bps data stream would require a minimum sinewave subcarrier of 1024 Hz and the lowest bit rate available for a 1000 Hz subcarrier would be 1.953125 bps. For a 16000 Hz subcarrier, the bit or symbol rate can be between 7.8125 and 8000 bps. For a 250075 Hz subcarrier, the bit or symbol rate can be between 122.1069 and 125037.5 bps.

A 1 bps data stream would require a minimum squarewave subcarrier of 128 Hz and the lowest bit rate available for a 100 Hz subcarrier would be 1.5625 bps. For a 1000 Hz subcarrier, the bit or symbol rate can be between 1.953125 and 500.

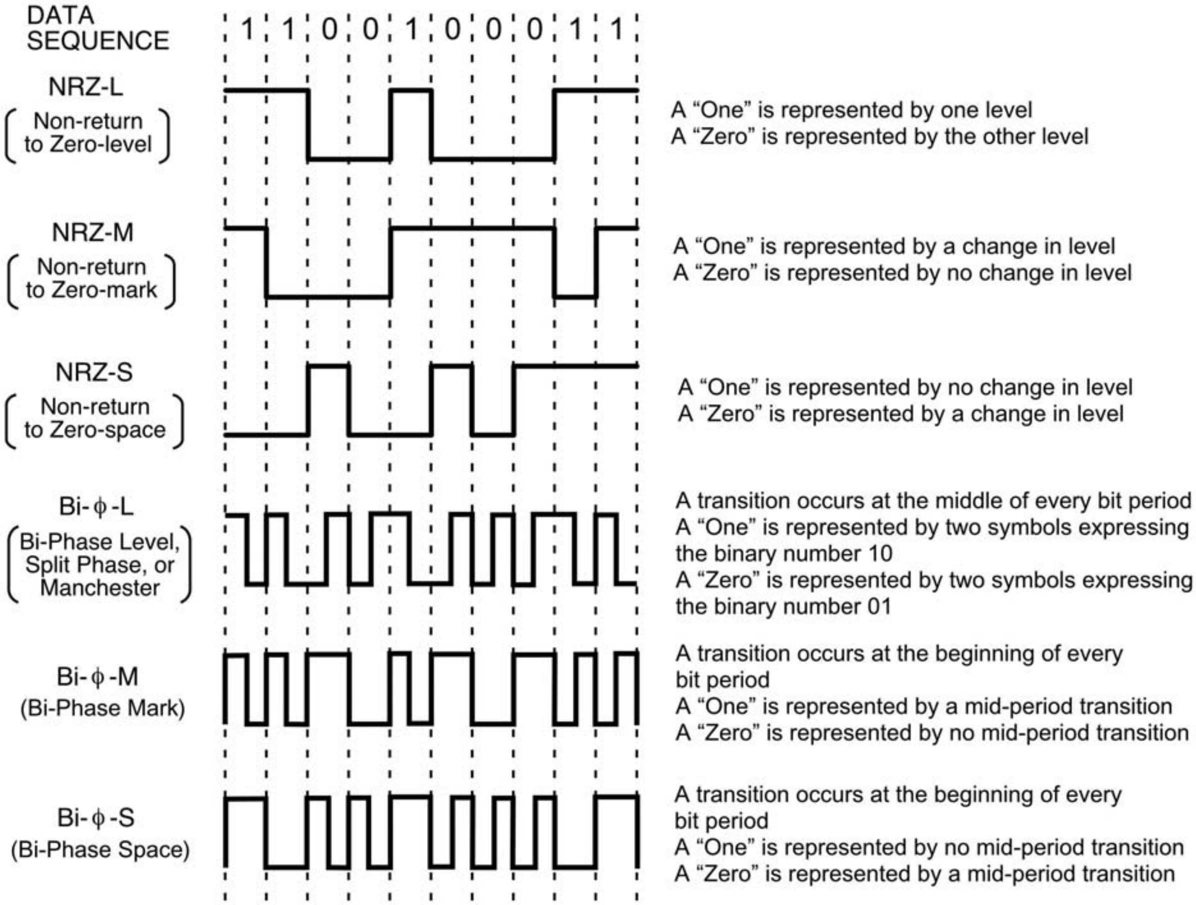

Figure 6. Command Data Formats

The data rate entry in the activity service table is rounded to the nearest acceptable value depending on the subcarrier frequency selected. The data rate may be changed during a support activity providing no command waveform is being radiated. However, a data rate change will have no effect unless it is large enough to cause a different binary divisor to be calculated. Small changes in subcarrier frequency will result in an equivalent change in data rate. A specification of a data rate midway between two valid data rates may result in a change in the binary divisor when the subcarrier frequency is changed.

3.8 Idle Patterns

The DSN command equipment can be configured to operate in three modes during a command support activity. The command mode is initialized from an entry in the activity service table but may be changed during a support activity providing no command waveform (subcarrier or subcarrier and data) is being radiated. The first of these is carrier only as might be used during a support activity not involving commands. In this mode, all command modulation is removed whenever command data are not being radiated. The second mode is subcarrier only in which a continuous, unmodulated subcarrier is transmitted to the spacecraft at the specified frequency and modulation index. The third mode is subcarrier with a customer defined 8-bit idle pattern. Samples of idle patterns are: all zeros, all ones, or alternating zeros and ones. If a sequence cannot be specified as an 8-bit pattern, it must be originated at the MOC or POCC as command bits. The transition between an idle pattern and command bits can only occur at 8-bit boundaries.

3.9 Command Timing

The customer may specify a first bit radiation time within the command data stream to an accuracy of 0.1 s. If an idle pattern has been specified, the actual first bit radiation time will be from 1 to 8 bit times later than the specified radiation time. Commands will be radiated upon receipt if no first bit radiation time is specified. If contiguous radiation of commands is desired, it is the customer's responsibility to ensure that the commands are delivered at a rate sufficient to satisfy the radiation requirements while not overflowing the buffering capability of the command equipment. Further details can be found in 820-013 module 0163-Telecomm (SLE Command).

3.10 Command Verification

The command equipment constantly monitors the output of the exciter to verify that the requested modulation index is within acceptable limits. No test on data content is performed because there is no independent source of data available for comparison. In addition, the transmitter power level, waveguide configuration, presence of frequency and timing references, and software health are monitored. Failure of a monitored parameter will cause a command abort. Exciter, transmitter, and microwave monitoring may be disabled upon customer request.

3.11 Availability and Reliability

The DSN Command System availability is 98.9 percent. The mean time between command aborts is 2200 hours of command time. This number was obtained from analysis of several years of operational data at the Goldstone DSCC involving the previous generation of command equipment. The number is considered valid because most aborts were caused by factors external to the command equipment.

There is no history available from which an undetected command bit error rate can be determined but it is believed to be significantly less than 3 in 10^8 transmitted bits and may be as low as 1 in 10^{13} which is the error rate of the communications channel between the customer and the stations.

3.12 Emergency Support

The DSN Command System provides a means for replay of command files that have been recorded earlier and stored at the station for emergency use during periods when communications between the MOC or POCC and the station cannot be established. The procedure for using these command recordings is covered in document 810-007, DSN Mission Interface Design Handbook (not yet published).

4 Proposed Capabilities

The following capability has not yet been implemented by the DSN but has adequate maturity to be considered for spacecraft mission and equipment design. Telecommunications engineers are advised that any capabilities discussed in this section cannot be committed to except by negotiation with the Interplanetary Network Directorate (IND) Plans and Commitments Program Office.

4.1 Direct Carrier Modulation

A partial implementation of the CCSDS Medium Rate Command Recommendation (CCSDS Recommendation 401.0B, paragraph 2.2.7) will be implemented. NRZ bit rates and bi-phase symbol rates of 8000, 16000, 32000, and 64000 will be available. Bit or symbol rates in excess of 64000 bps/sps will not be available due to exciter bandwidth restrictions. Carrier and data suppression for direct carrier modulation is calculated using the equations for squarewave modulation (3) and (4).

Appendix A
References

1 CCSDS 727.0-B-4, CCSDS file Delivery Protocol, Blue Book, January 2007.

2 CCSDS 401.0-B-18, Recommendations for Radio Frequency and Modulation Systems, December 2007.

3 CCSDS 912.1-B-2, Space Link Extension – Forward CLTU Service Specification, Blue Book, November 2004.

4 810-007, Deep Space Mission System Mission Interface Design Handbook, to be published.

5 820-013 module 0163-Telecomm, Space Link Extension Forward Link Service, Revision C (release pending).

6 820-013 module 0213-Telecomm-CFDP, Deep Space Network (DSN) Interface for the CCSDS File Delivery Protocol (CFDP), Revision A, May 29, 2009.